A CONSEQUENCE ANALYSIS METHOD FOR OUT OF AREA FIELD STORAGE

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Abstract

AASTP-5, Part II establishes North Atlantic Treaty Organisation (NATO) guidelines for the storage, maintenance and transport of ammunition during deployed missions and operations. It assists in the planning, reconnaissance and establishment of an Ammunition Area and the management of the ammunition. The document is designed for use by the Operational Commander's specialist.

AASTP-5, Part II, defines - as a main part - the Field Distances (FDs) to be kept between PES (Potential Explosion Site) and PES (preventing prompt propagation of explosions) and between PES and ES (Exposed Site) (ensuring an appropriate safety level for exposed personnel and public). In cases where these FDs cannot be applied, e.g. due to lack of available area or tactical mission requirements, a consequence and/or risk analysis has to be conducted before making a decision to deviate from the FDs.

NATO AC/326 (CNAD Ammunition Safety Group) has asked CHE and NLD to develop a consequence and risk analysis method to be incorporated in AASTP-5, Part II. For this purpose BK&P has developed the general outline of the method, while TNO Defence, Security and Safety calculated the explosion effects and consequence data. The consequences are expressed in terms of lethality, injury, and damage to assets. The method enables to take into account protective measures like barricades, and overhead protection, and distinguishes between different types of structures relevant to Out of Area (OoA) operations. This paper describes the results obtained so far.

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14. ABSTRACT
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1. Introduction

AASTP-5, Part II establishes North Atlantic Treaty Organisation (NATO) guidelines for the storage, maintenance and transport of ammunition during deployed missions and operations. It assists in the planning, reconnaissance and establishment of an Ammunition Area and the management of the ammunition. The document is designed for use by the Operational Commander's specialist.

AASTP-5, Part II, defines - as a main part - the Field Distances (FDs) to be kept between PES (Potential Explosion Site) and PES (preventing prompt propagation of explosions) and between PES and ES (Exposed Site) (ensuring an appropriate safety level for exposed personnel and public). In cases where these FDs cannot be applied, e.g. due to lack of available area or tactical mission requirements, a consequence and/or risk analysis has to be conducted before making a decision to deviate from the FDs.

AC/326 has asked CHE and NLD to develop a consequence and risk analysis method to be incorporated in AASTP-5, Part II. BK&P was sponsored by armasuisse (former Defence Procurement Agency), and developed the general outline of the method. A proposal for an AASTP-5 risk analysis chapter was documented in a NATO/PfP working paper (Kummer, 2007). A description is given in Section 2.

TNO Defence, Security and Safety was sponsored by the NLD MoD (Military Committee for Dangerous Goods, Section MCGS), and has calculated the required explosion effects and consequence data. The FDs given in AASTP-5, Part II are based on a probability of lethality of 1 %, and have been derived in an earlier joint NLD/CAN project (Anderson, 2008). In a consequence and risk analysis, information about higher lethality levels is required as well. This has led to the definition of Higher Risk FDs (HRFDs). The assumptions made for the calculation of these HRFDs have been reported in an informal working paper (van der Voort, 2009-2).

Figure 1. A compound and the relation between threats, resources, essential operational capabilities (EOC), and the mission goal

During the project AC/326 requested to extend the lethality calculations towards injury and damage to assets. The knowledge developed by TNO within research programs V402 Safety of Personnel and V817 Protection and Survivability of compounds has been applied for this purpose. Within V817 the (accidental) detonation of an ammunition storage site is just one of many possible threats to compounds. The goal of this research program is to develop a cost-

benefit analysis method for a variety of countermeasures; related to both physical protection and situation awareness (Van der Voort, 2010-2).

Some of the countermeasures that are taken into account in V817 have also been adopted for the derivation of the HRFDs. These are the blast and ballistic resistance of various structures, barricades, overhead protection, and windows. The assumptions and models used for the calculations are described in Section 3. The calculation results are discussed in Section 4.

2. General outline of the consequence and risk analysis method

2.1 Aim

The consequence and risk analysis methodology proposed by NLD and CHE for field storage situations aims at giving a commander a fast overview on the expected damage in terms of:

- number of persons that might be killed,
- number of persons that would be substantially injured,
- material damage,
- loss of mission,

in case of an accidental or enemy action related explosion in an ammunition or explosives storage structure.

2.2 Basic requirements

A consequence and risk analysis method for field storage situations should fulfil the following 5 requirements:

1) The result must be quantitative, concise and convincing
   → qualitative figures are not sufficient!
2) The procedure must be easy to carry out and must be understandable
   → only limited training for Explosive Safety Officers might be possible
3) The procedure must be lean
   → associated paperwork should be kept to a minimum
4) Implementation in an easy to use low cost computer tool should be feasible
   → e.g. EXCEL based code
5) Directions how to manage the consequences/risks must be given
   → only to calculate number is not enough!

2.3 Proposed consequence calculation method

Based on the requirements listed above the following approach is proposed:

Step 1) Collect basic data on:
- Type, location and loading (NEQ) of PES
- Type and location of possible ESs
- Number of persons in each ES
- Distance between PES an all ESs

Preferably results should be presented on a map (example Figure 2).

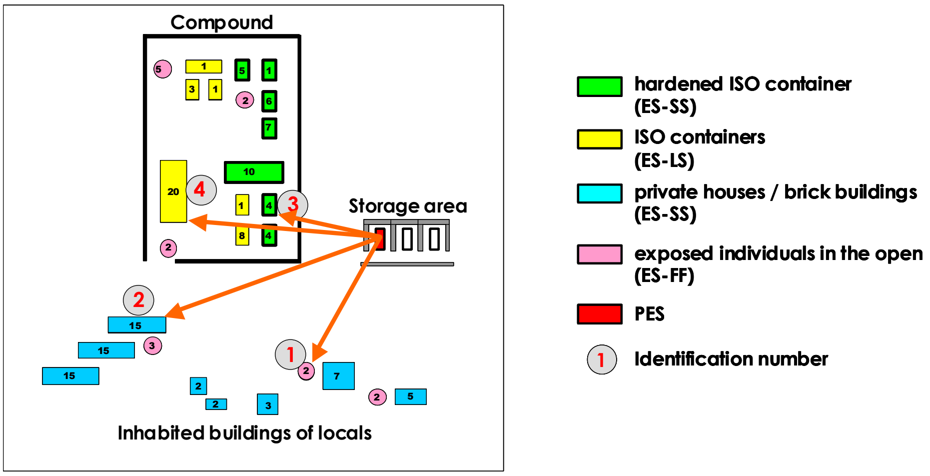


Figure 2. Example of a typical field-storage situation, showing a number of different exposed sites ESs and number of exposed persons in each ES

Step 2) Calculate the lethality and injury of persons and the damage to each ES, based on:

- Type and loading (NEQ) of PES
- Type of ES
- Distance between PES and ES

This step can be done using either tables provided in AASTP-5 or with a software tool (see Chapter 5). A simplified (fictional) version of a lethality table is given in Figure 3. Note: The main part of this paper deals with the derivation of the lethality values presented in the table below.

1-FF	Parking Lot	125 m
2-SS	Inhabited Building	170 m
3-SS	Sleeping Container	105 m
4-LS	Canteen	145 m

Lethality Table		CB-4000		
PES - 20ft - Container with Barricade			NEQ = 4000 kg	
Distance	Exposed Sites			
between PES and ES [m]	ES-FF free field [%]	ES-LS light structures [%]	ES-SS semi-hardened structures [%]	ES-HS hardened structures [%]
0 - 10	100	100	100	100
10 - 20	100	100	100	80
20 - 30	100	100	80	50
30 - 50	100	80	50	10
50 - 75	100	50	25	5
75 - 100	100	25	10	1
100 - 150	50	10	2	0.1
150 - 200	10	2	1	0
200 - 300	5	1	0.1	0
300 - 500	1	0.1	0	0
500 - 750	0.1	0	0	0
750 - 1000	0	0	0	0

Figure 3. Example of a simplified damage (lethality) table, showing the probability of lethality for people staying in the 4 ESs identified in Figure 2.

Step 3) Assess the Consequences for a given situation by:

- Filing the lethality values into the consequence calculation table
- Multiplying the lethality values with the number of exposed persons in the respective ESs
- Adding up these results of all ESs

This step can be performed manually or with the software tool (see Chapter 5). The result will be a number of people possibly killed in case of an event in the examined PES. With a similar procedure injuries and damage to assets may be calculated.

Location: Compound NewLand								
Case Number: 101			Case Description: Average consequences due to an explosion in container 1					
PES Type: barricaded ☒ unbarricaded ☐								
PES Number: Container 1								
NEQ [kg]: 4000 kg								
Map Scale 1: xx								
Analysis performed		Date:		by:				
Object No.	Object Type	Object Description	Distance PES - ES [m]	No. of Table used	Lethality [%] A	Number of Exposed Persons B	A x B [%]	Re-marks
1	ES - FF	Parking Lot	125		50	2	100	
2	ES - SS	Inhabited Building	170		1	15	15	
3	ES - SS	Sleeping Container	105		2	4	8	
4	ES - LS	Canteen	145		10	20	200	1)
Total of all exposed objects						Σ AxB = C	323	
Expected number of fatally injured persons						C / 100	3	
Remarks: 1) 25 persons during daytime, 15 persons during night time = 20 persons in average								
Appro-ved:	Date:		Signature:					

Figure 4. ***Example of a simplified consequence calculation table, showing the calculation of the expected number of fatally injured persons for the situation given in Figure 3 (for ESs 1-4)***

2.4 *Risk management in the AASTP-5 context*

Generally speaking, risk is a combination of consequences (as calculated above) and the probability that an unwanted event (explosion) occurs. The probability of explosion in a field storage situation depends, among others, on two main factors:

- The type of ammunition that is stored
- The influence of enemy actions

Approximate values for probabilities in field storage situations may be found in AASTP-4, Part II.

Finally, whenever the field distances (FD) according to AASTP-5 cannot be followed a consequence and risk analysis as described above must be carried out. The result of this process should be documented and issued as a waiver. Such a waiver should at least give answers and advice on the following points:

1) Why was it necessary to deviate from the field distances?
2) What consequences and risks will this imply?
3) What measures were taken to reduce the consequences and risks, and what is the effectiveness of these measures?

4) How to respond to an emergency, taking into consideration all special circumstances?
5) How to permanently supervise the measures taken, the consequence and risk level and all the contributing factors like the type and amount of ammunition stored, the number and location of the exposed persons, etc.?

3. Effect and consequence modelling

3.1 Phenomena

The (accidental) mass detonation of an ammunition storage site can cause injury and lethality to military personnel, and damage to the compound infrastructure. The types of injury are related to the (combined) blast, fragment, and thermal load generated by the explosion. An overview is given in Table 1. From this table becomes clear that for people in the free field the possible causes of blast injury are limited to auditory injury, injury to the internal organs (i.e. lungs), and blunt trauma after acceleration of the body (whole body displacement). People residing in structures are protected by a certain level of ballistic resistance against fragment impact, but are on the other hand exposed to glass shards from windows (if present) and blunt trauma due to structural damage or failure (collapse). Dependent on the load, the types of injury shown in Table 1 can all lead to lethality, except for auditory injury. Types of injury related to the thermal load have not been considered as these can be neglected with respect to the other ones.

Table 1. Types of injury in dependence of physical effects and situation of personnel

Physical effect	**Situation of personnel**	**Relevant types of Injury**							
		Auditory	Internal organs	Blunt impact (Whole body displacement)	Glass shard penetration (Window failure)	Blunt impact (structural damage/failure)	Fragment/projectile penetration	Skin burns	Intoxication / Asphyxia
Blast load	Free field	X	X	X					
	Inside structure (with blast damage)	X	X	X	X	X			
Fragment/ Projectile load	Free field						X		
	Inside structure (with penetration damage)						X		
Thermal load	Free field							X	
	Inside structure (without ventilation / fire resistant doors)							X	X

3.2 Physical Protection

In field camps various physical protection measures are applied to reduce the explosion effects and consequences described above. It was thought to be essential to take the most important measures into account in the derivation of the HRFDs.

Structures occurring Out of Area (OoA) have been categorized in the following ES structure types (in order of increasing ballistic resistance (Figure 5)):

- FF: Free field
- Tent
- LS: Light Structure (container with 12.5 mm multiplex / 0.75 mm steel walls)
- NS: Normal Structure (ISO-container with 2 mm mild steel walls)
- RS: Reinforced Structure (container with 5 mm mild steel walls)
- HRS: Heavily Reinforced Structure (container with 2*8 mm armoured steel)
- HESCO structures (thickness 0.8-1 m, filled with sand)

Figure 5. Examples of ES structures: tent,' normal (ISO)', heavily reinforced, HESCO

Additionally, to characterize domestic buildings outside the compound:

- IB: Inhabited buildings (typical NLD domestic house)

Barricades constructed from HESCO bastions will stop virtually all fragments impacting at low angles. The situation is called barricaded if a barricade is placed either close to the PES, close to the ES or both (Figure 6). Two options are taken into account:

- Unbarricaded
- Barricaded

Overhead Protection (OHP) at the ES will stop virtually all fragments impacting at high angles. Two options are taken into account:

- No OHP
- OHP

Figure 6. ***Physical protection of an ES structure with barricades (HESCO) and overhead protection***

In ‘light’ and ‘normal (ISO)’ structures double annealed windows are applied in some cases (Figure 7). In the event of an explosion, window breakage may give rise to an additional hazard due to glass shard impact. When blast resistant windows or no windows are used this is not the case. Two options are taken into account:

- Typical OoA double annealed windows
- Blast resistant windows or no windows

Figure 7. ***ES structure with double annealed windows***

3.3 Modelling

The various options for physical protection described above result in a large number of PES versus ES combinations. The calculation of the effects and consequences (injury, lethality and damage) for each of these cases has been carried out with Risk-NL v5.0 (Van der Voort, 2010-1, 2009-1). This is a risk assessment software tool for the external safety of ammunition storage sites. A screen shot is given in Figure 8 showing the risk contours from reinforced concrete magazines.

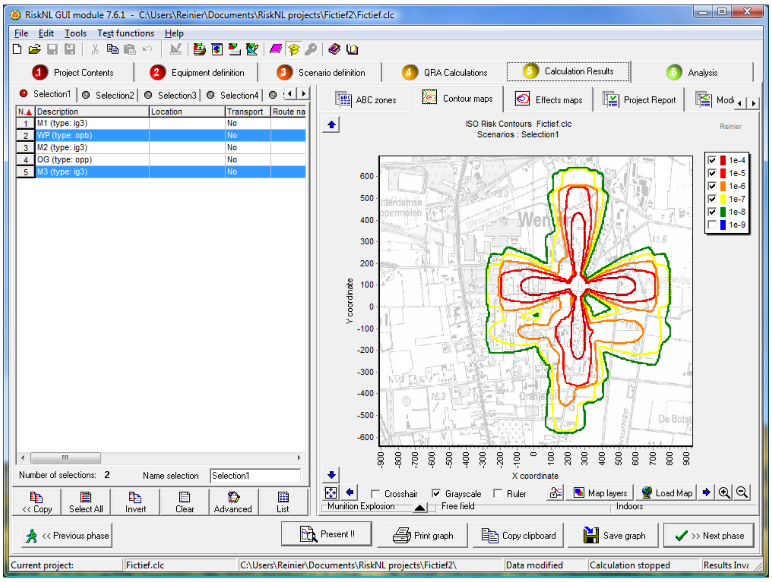


Figure 8. ***Screenshot of Risk-NL v5.0 showing risk contours of reinforced concrete storage magazines.***

For this purpose the Risk-NL v5.0 PES model for cased HD1.1 ammunition in an ISO container has been used (Van der Voort, 2008). This model is validated against a number of full scale trials (Anderson, 2006 & 2008, and van der Voort, 2008)

In the model the stored HD1.1 is translated to a square stack of vertically placed 155 mm artillery shells. The model distinguishes between fragments launched from shells at the side of the stack, and from shells in the bulk of the stack. The first category behaves as single detonating shells, while the bulk of the stack behaves radically different. These shells fragment into much larger fragments, which are directed primarily upwards. The fragments are launched with a velocity that is twice the single shell velocity (TP 16).

The model described above does not take into account debris from the PES structure (ISO container) itself. Recently the ISO test series have been carried out (Swisdak, 2009). The test results show that the contribution from ISO debris is negligible compared to the primary fragments (at least for higher loading densities). This also follows from Figure 9 where the IBD is shown for both ISO debris and fragments.

If an OHP is present at the PES, primary fragments and container debris launched upwards will be partly stopped or strongly decelerated. On the other hand, material from the OHP itself (wood, dirt) is thrown. The PES model described above does not take into account these effects. Test results from (Anderson, 2006) have shown that the number of OHP debris is so small that its contribution in terms of hit probability can be neglected compared to the primary fragments.

The Abbreviated Injury Score (AIS) criterion has been used to characterize the injury. A distinction is made between AIS ≥ 1 (briefly called injury), and AIS ≥ 5 (briefly called lethality). With respect to fragment penetration injury it is assumed that only hits in the head, thorax and abdomen may lead to lethality. Averaged over different body orientations these body parts comprise around 40 % of the frontal body area. Fragment hits in other body parts are assumed to result in a non-lethal form of injury.

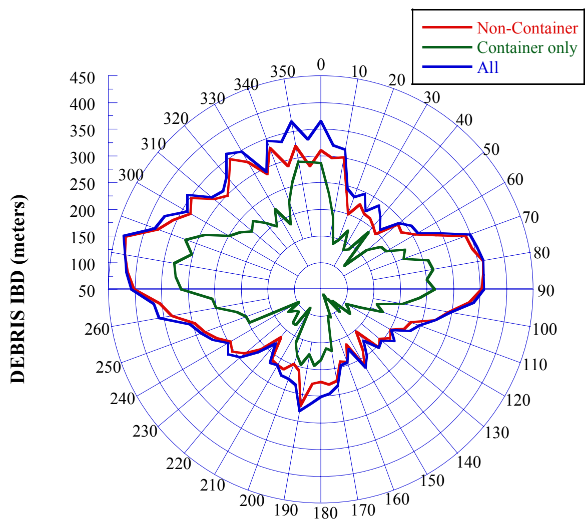


Figure 9. ***Debris IBD due to primary fragments (red) and container debris (green) after the ISO-3 trial; detonation of 1000 kg case ammunition in an ISO container (Swisdak, 2009).***

Risk-NL v5.0 has been extended with new models for the specific blast - and ballistic resistance of the ES structures listed before. The ballistic resistance of the ES structures against natural fragments is expressed in terms of the ballistic limit velocity, and has been displayed in Figure 10. The V_{50} values are determined with the Thor equations, with an assumed impact angle of 90°. The figure shows that realistic fragment masses at terminal velocity are not able to penetrate the roof of 'normal (ISO)' structures or structures with a larger ballistic resistance. The ballistic resistance of tents is negligible.

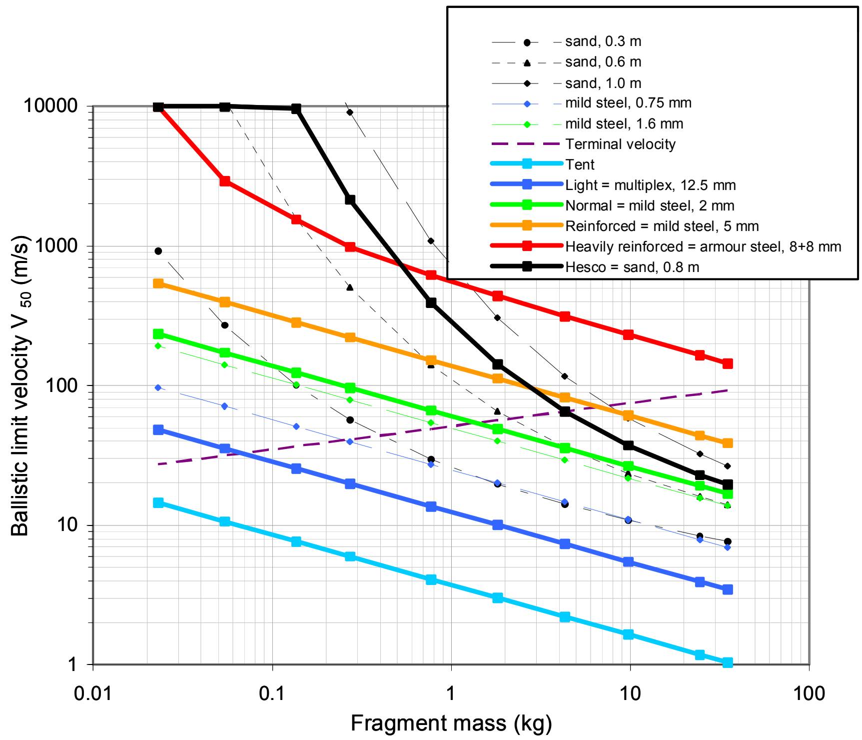


Figure 10. ***Ballistic limit velocities versus fragment mass for various structure types.***

The prediction of the blast resistance of ES structures is based on the TNO OoA database, a large collection of experimental data from full scale trials (Sibma, 2009). The data has been divided in three categories: 'No damage', 'Damage', and 'Failure'. These categories are defined by a ductility (Du) criterion; respectively Du ≤ 2, 2 < Du ≤ 10, and Du > 10. The experimental data is supported by SDOF calculations. Experimental data and calculated Pressure-Impulse (P-I) curves for 'normal (ISO)' structures are shown as an example in Figure 11.

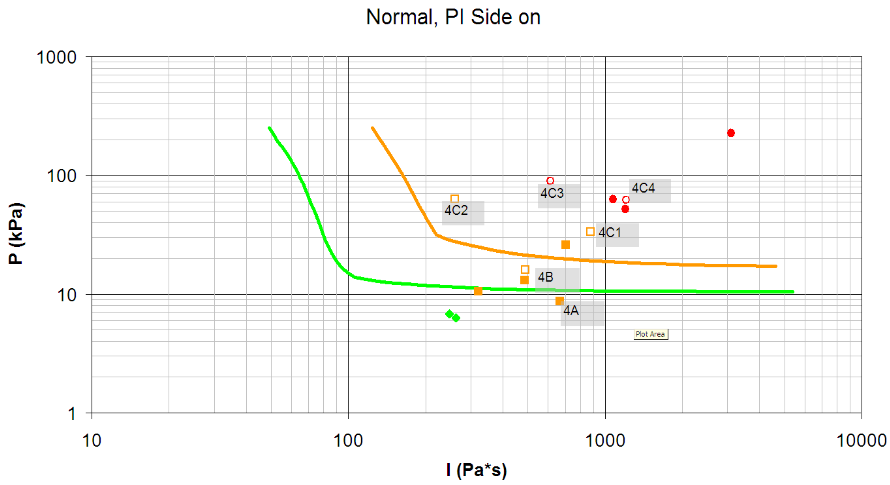


Figure 11. ***Experimental data and P,I curves from SDOF calculations representing thresholds for damage (green), and failure (orange) for 'normal (ISO)' structures.***

The distances at which the Du = 2 and Du = 10 values are reached are shown in Figure 12 for a number of ES structure types. From SDOF calculation results Quantity Distance relations have been derived with trend lines to the data.

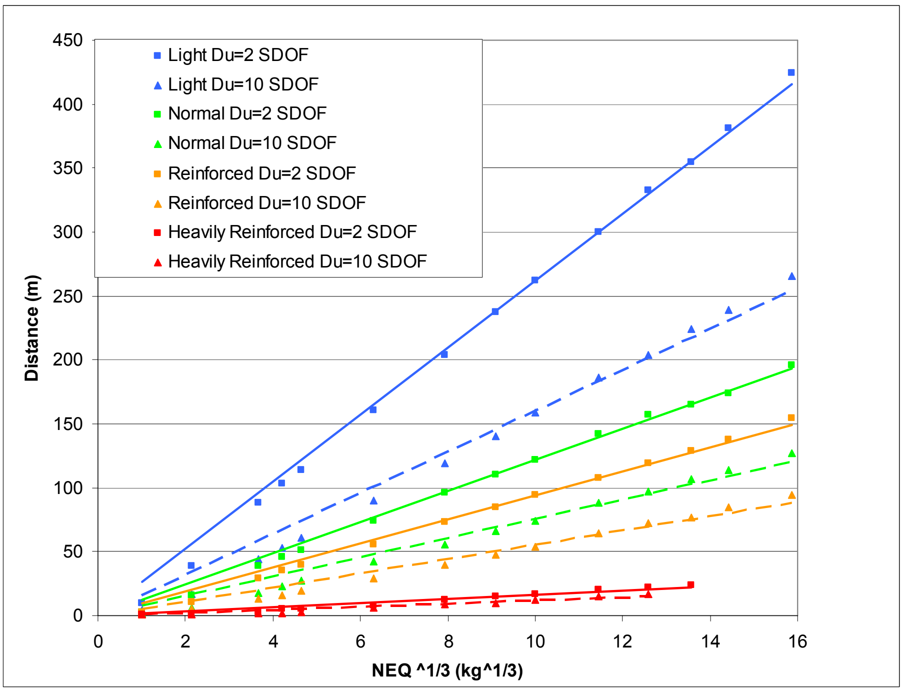


Figure 12. ***Du=2 and Du=10 distances versus NEQ^1/3 for various structure types. SDOF calculation and data fit.***

Around the damage and failure threshold, the probability of injury and lethality due to structural response has been estimated. These estimates are based on the velocities that walls and objects in the ES structures will obtain and the affected area in relation to personnel. At present a maximum probability of lethality of 35 % (based on earth quake data) has been posed at large over loadings. However, this value may vary depending on the type of structure and will be investigated in the future in more detail. The probability of lethality at an arbitrary blast load has been estimated with probit functions. Figure 13 shows probit functions for various structures in dependence of the peak overpressure asymptote (reflected value). A similar graph exists as a function of the impulse asymptote. It is assumed that the surviving people in a collapsed structure have at least some form of injury (AIS≥1).

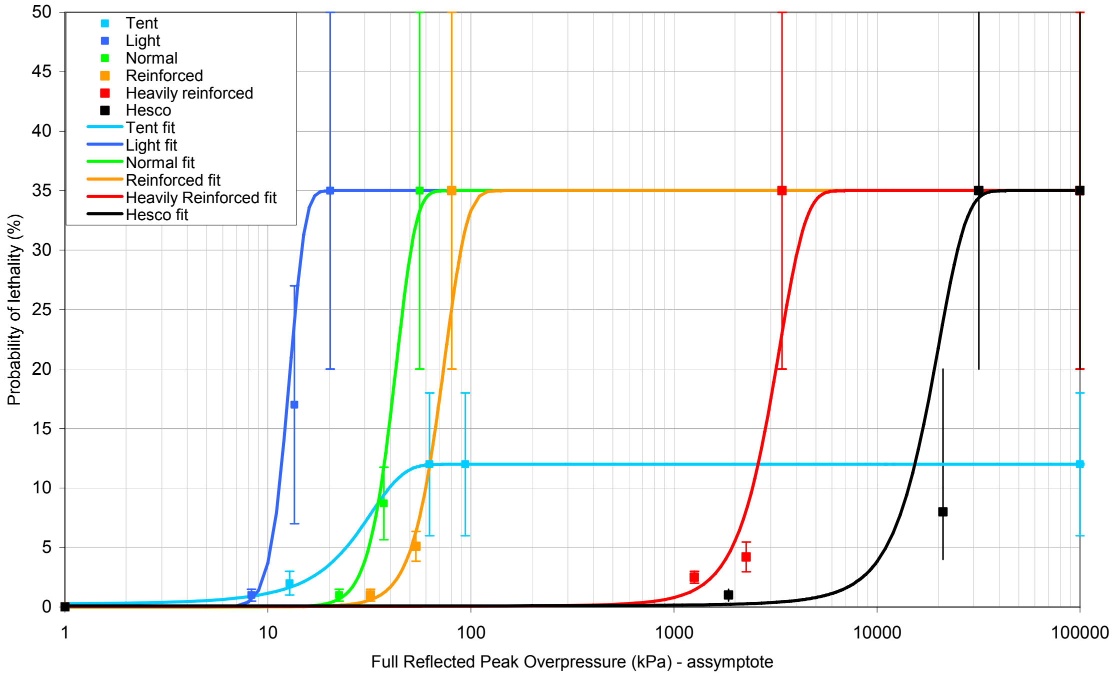


Figure 13. ***Probability of lethality due to structural response as a function of the reflected peak overpressure asymptote.***

Furthermore a new window failure model (Van Doormaal, 2010) has been developed for typical OoA windows with double annealed glazing (thickness 4 + 5 mm) and dimensions (area 0.5 - 0.9 m^2). The model consists of a prediction of the probability of window failure and the probability of lethality (Figure 14). The probability of window failure depends on both overpressure and impulse. The probability of lethality only depends on the impulse, because it is the impulse that determines the glass shard velocity. It is assumed that there is a reflected blast load and that 25 % of the people have a line of sight perpendicular to window panes.

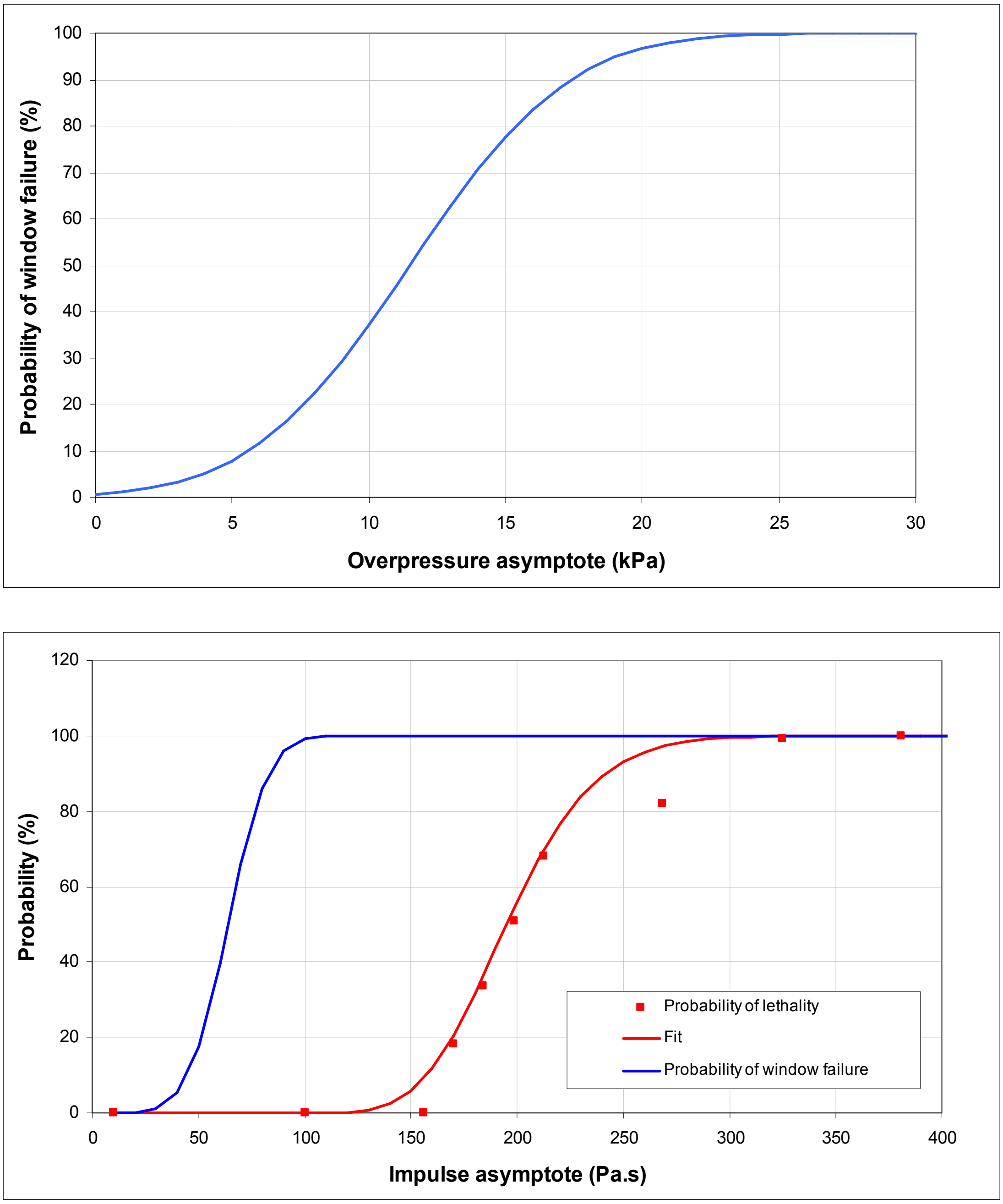


Figure 14. Probability of window failure and lethality versus overpressure and impulse asymptote.

For auditory injury a relation between the probability of auditory injury (tympanic membrane rupture) versus scaled distance has been derived. This relation is based on the original data of (Hirsch, 1968). The result is displayed in Figure 15.

It is assumed that personnel in structures are loaded with the free field side-on blast wave; blast ingress phenomena are not considered. An exception are the HESCO structures, for which a reduction of 25 % is applied to the overpressure. This is consistent with the assumptions made by (Anderson, 2008).

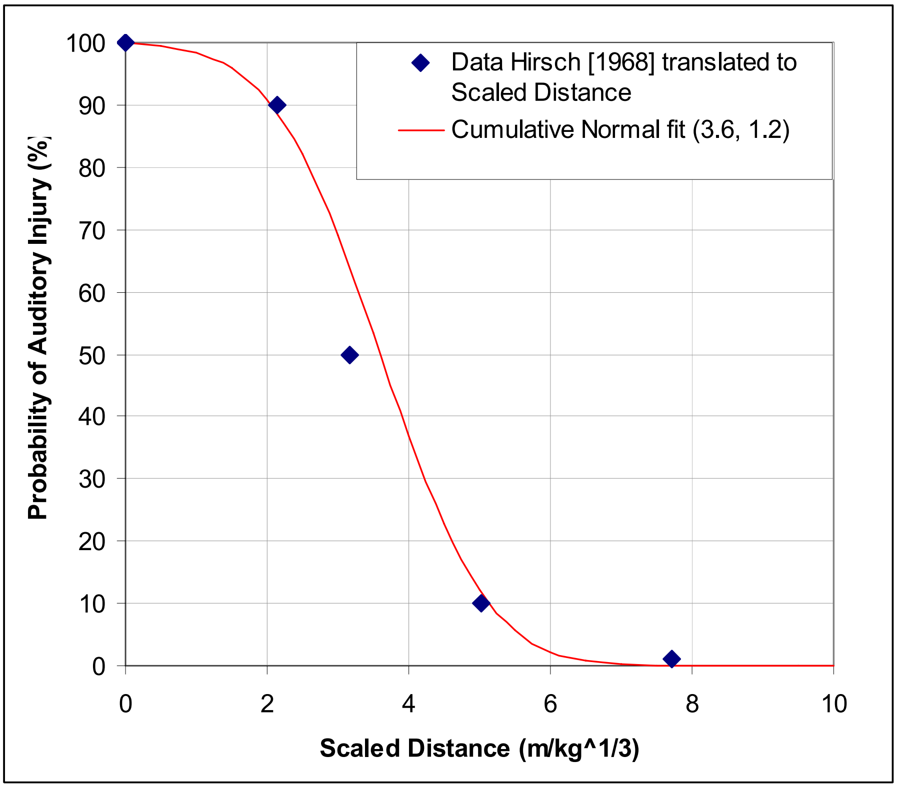


Figure 15. Probability of auditory injury (tympanic membrane rupture) versus scaled distance ($r/NEQ^{1/3}$)

4. Results

Figure 16 gives an illustration of the contributions from the various causes of lethality. The PES is here an ammunition storage site with 4000 kg TNT equivalence, and the ES is a 'light structure'. A distinction is made between fragments launched around the horizontal direction (from the side of the ammunition stack), and around the vertical direction (from the bulk of the ammunition stack).

From Figure 13 follows that there are multiple causes of lethality simultaneously relevant. Close-in the primary fragments are dominant. They cause 100 % probability of lethality up to about 100 m. Lethality due to structural response takes over at about 150 m, while window failure becomes the most important phenomena beyond 300 m. In the far field fragments impacting with terminal velocity are the last remaining hazard. If windows are present window failure determines the 1% lethality distance (at 440 m), if not, terminal fragments determine the 1 % lethality distance (at 360 m).

It is concluded that a consequence and risk analysis method can not be based on one lethality mechanism only. Furthermore, knowledge about the separate lethality mechanisms is essential to account for the physical protection measures; barricades stop horizontal fragments, while OHP stops vertical fragments, and the presence of windows determines whether the window failure curve is relevant. Lastly Figure 16 shows that lung injury and head and body impact are only relevant phenomena when horizontal fragments are blocked, and when structural response and window are not relevant. This is only the case for persons in heavily reinforced and HESCO structures, or persons behind a barricade in the 'free' field.

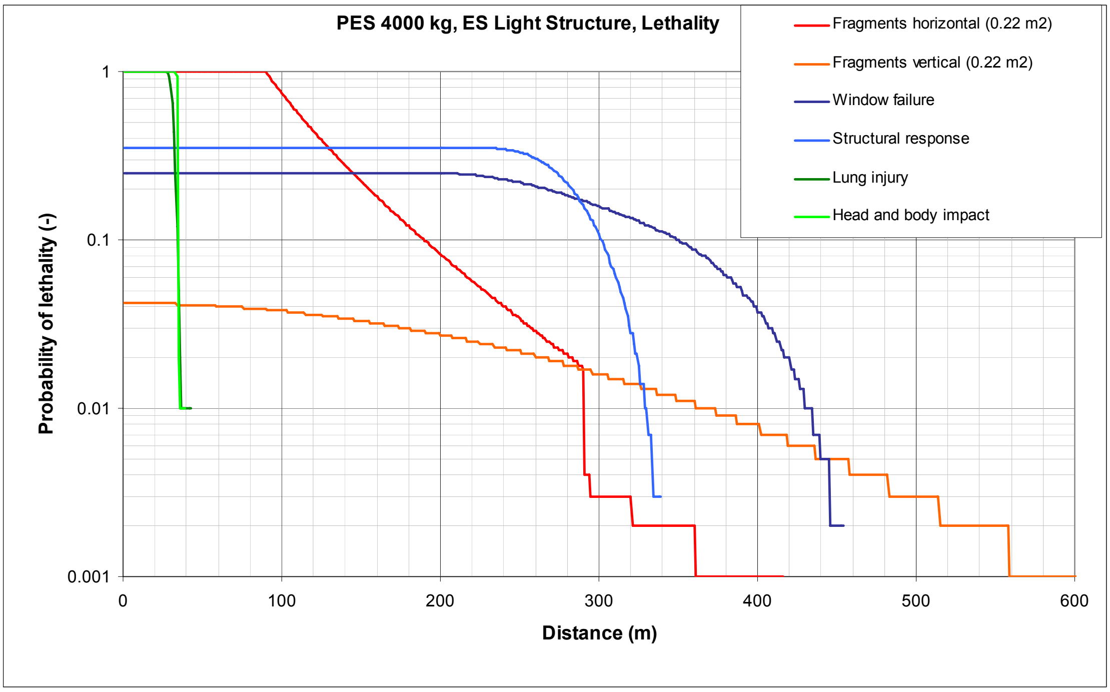


Figure 16. Probability of lethality (AIS ≥5) versus distance; contributions from the various mechanisms.

Figure 17 shows contributions from types of <u>injury</u> for the same situation. An additional curve appears for auditory injury. Relative to Figure 13 the horizontal and vertical fragment contributions have increased due to the larger body area responsible for injury. The curve for structural response also shifts up because the surviving people in a collapsed structure are at least injured.

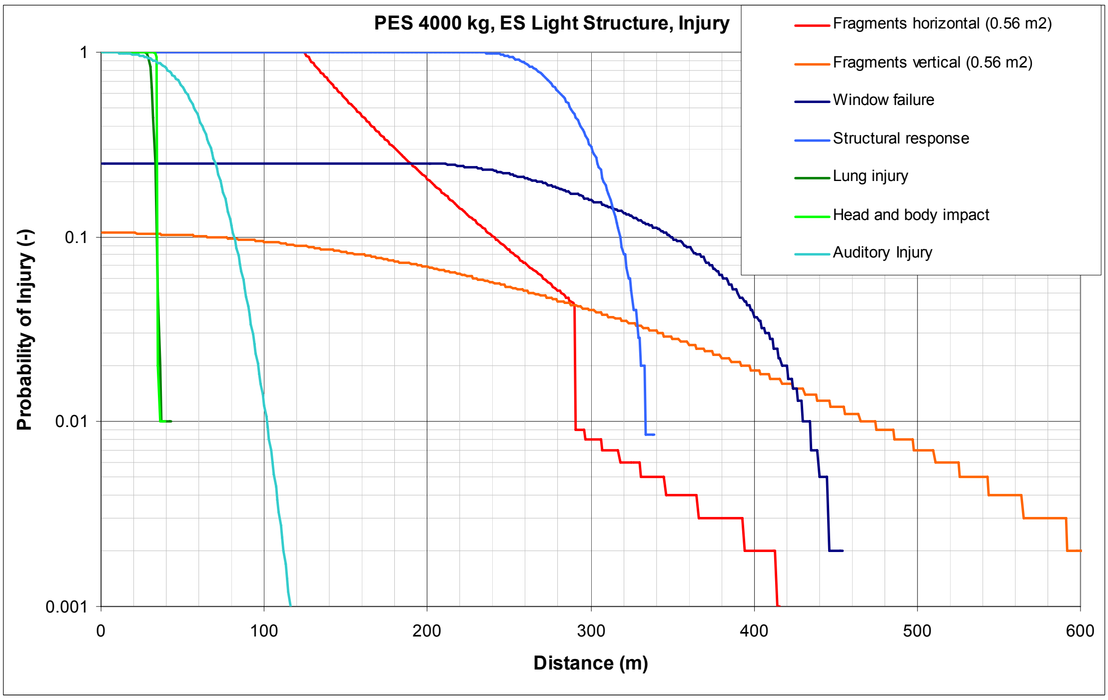


Figure 17. Probability of injury (AIS ≥1) versus distance; contributions from the various injury types.

Figure 18 gives the distance at which the probability of lethality drops below 1 % as a function of the Net Explosive Quantity (NEQ) running from 50 to 4000 kg. Results are shown for various combinations of countermeasures. The figure shows that in the close-in regime a barricade is most efficient. The curves tend to split-up in two branches; one with barricades (BS), and one without barricades (UBS). The figure also shows that in the far field regime an appropriate window design is most efficient (the curves tend to split-up in two branches; one with OoA windows, and one without windows or with blast resistant windows). When (again in the far field) windows are not present, an OHP is efficient.

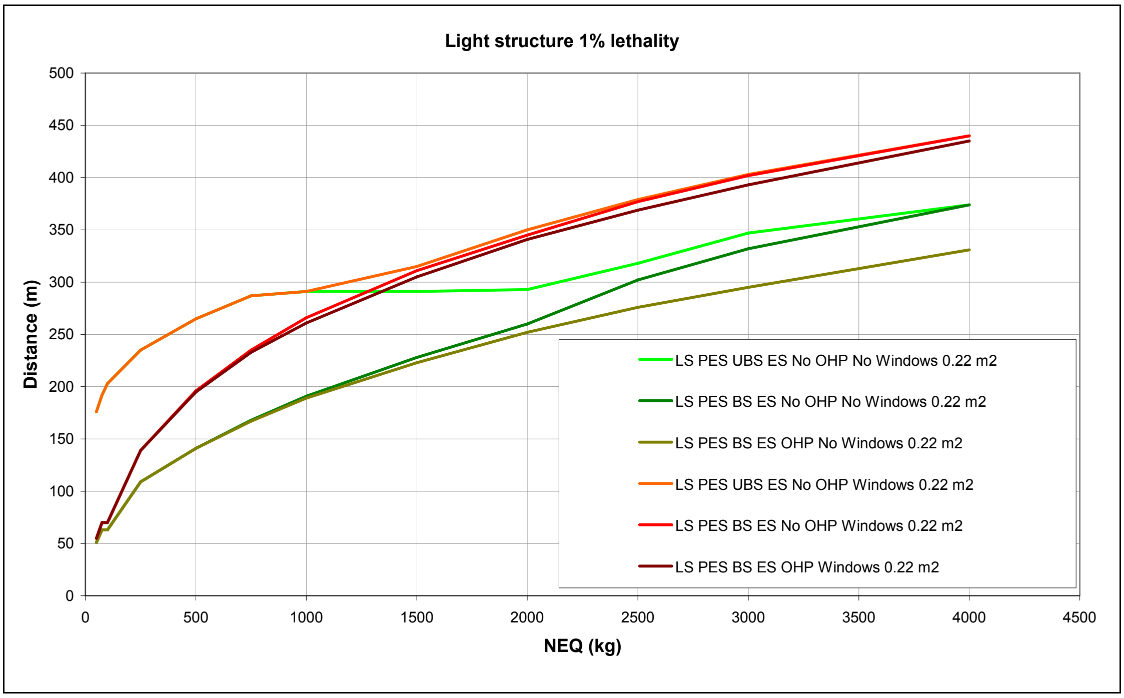


Figure 18. ***1% lethality distance for personnel in 'light' structures versus NEQ for a variety of counter measures***

5. Conclusions

TNO Defence Security and Safety and BK&P have developed a consequence and risk analysis method for OoA field storage. The method enables the Operational Commander to perform a quantitative analysis of the consequences related to a detonation of the ammunition storage.

The method consists of tables for a variety of ES structures, NEQ, and physical protection measures like barricades, OHP, and window design. The underlying calculations have been carried out with Risk-NL v5.0, which has been extended with sub models for Out of Area ES structures. The results show that multiple types of injury are often simultaneously relevant. The right level of detail was adopted to account for the physical protection measures.

The output of the tables consists of a prediction of the probability of lethality, injury, and damage to assets. To make the analysis user friendly the tables are currently being implemented in and Excel tool. An impression is given in Figure 19.

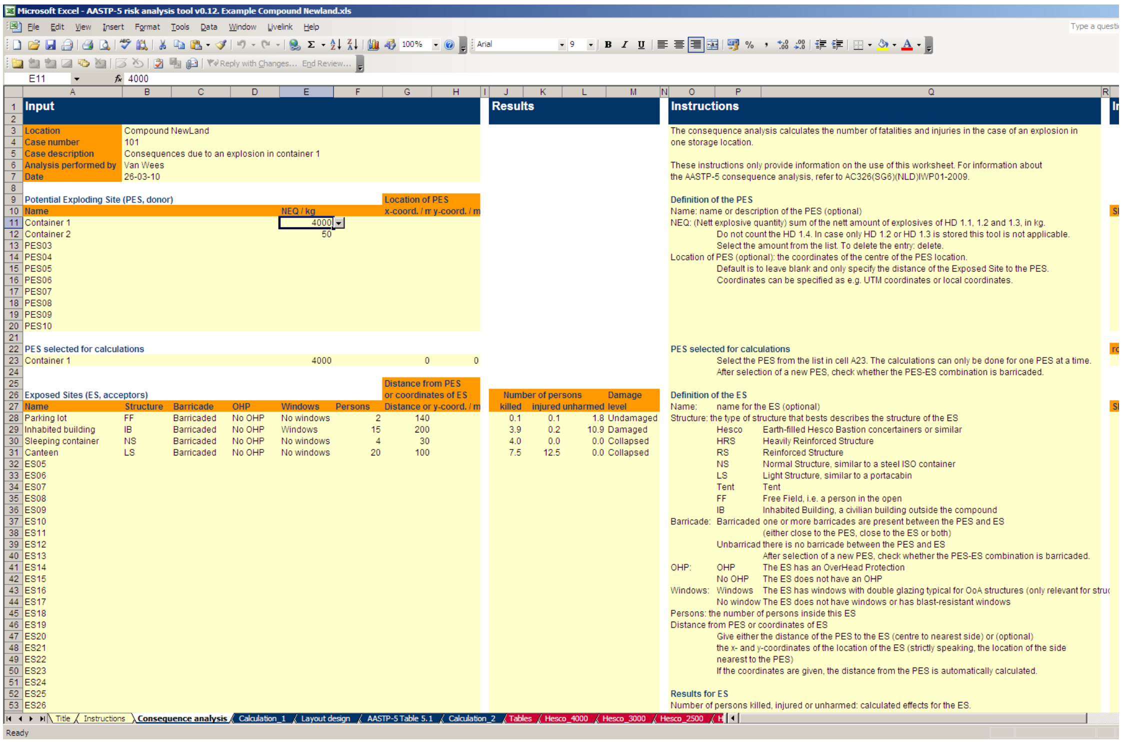


Figure 19. *Impression of the Excel tool (preliminary)*

References

AASTP-4, 2008
AASTP-4 *Allied Ammunition Storage and Transport Publication - Manual on Explosives Safety* Risk *Analysis*, Edition 1, Part I and II, Change 1, 2008

AASTP-5, 2007
AASTP-5 EDITION 1 - NATO Guidelines for the Storage, Maintenance and Transport of Ammunition on Deployed Missions or Operations, 2007

Technical Paper 16 rev 3, 2009
Methodologies for Calculating Primary Fragment Characteristics, Department of Defense Explosives Safety Board

Anderson, 2008
Dr. J. Anderson (DRDC), Dr. E.K. Verolme, M.M. van der Voort MSc (TNO)
PFP(AC/326-SG/6)WP(2008)0001 (NLD/CAN), *Assessment of the Field Distances Associated with the Operational Storage of Ammunition and Explosives of HD1.1*.

Anderson, 2006
Dr. J. Anderson (2006). *Presentation and fragment pick-up data TDM trials at the NATO AC326 SG5/6 Meeting 6-8 Sept. 2006.*

Hirsch, 1968
Hirsch, F.G. (1968), *Effects of Overpressure on the Ear - - A Review*. Technical Progress Report, DASA-1858, Defense Atomic Support Agency, Department of Defense, Washington, D.C., November 1966. Subsequently published in Ann. N. Y. Acad. Sci. 152: 147- 162 (October 28) 1968.

Kummer, 2007
PFP(AC/326-SG/6)WP(2007)0001, *AASTP-5, Part II, Proposed Risk Analysis Chapter*. TM 203-09, 13 March 2007 / Peter Kummer, (BK&P)

Sibma, 2009
Pieter Sibma, *Out-of-area structures subjected to blast; experimental and numerical data*, TNO-DV 2008 A446, March 2009.

Swisdak, 2009
Michael M. Swisdak, Robert. T. Conway, John W. Tatom. *ISO-3: Program Description and Progress*, Parari 2009.

Van der Voort, 2010-1
Martijn van der Voort, Reinier Sterkenburg, Ruud van Amelsfort, *The development of Risk-NL v5.0 and its applications,* 34th DDESB Explosives Safety Seminar 2010.

Van der Voort, 2010-2
Martijn van der Voort, Yoeng Sin Khoe, Wim van der Sluijs, Clarel Smit, *Development of a cost-benefit analysis method for compound protection and survivability*, European Survivability Workshop 2010, Aalesund, Norway.

Van der Voort, 2009-1
Martijn van der Voort, Ruud van Amelsfort, Rolf van Wees, Ans van Doormaal, *A description of Risk-NL v5.0,* TNO-DV 2009 A315, December 2009, Restricted.

Van der Voort, 2009-2
AC326(SG6)(NLD)IWP01-2009, *Assumptions for HRFDs for AASTP-5*, 30 November 2009.

Van der Voort, 2008
M.M. van der Voort, J.C.A.M. van Doormaal, E.K. Verolme, J. Weerheijm,
A universal throw model and its applications. Int J Impact Eng 35 (2008) 109-118, doi:10.1016/j.ijimpeng.2007.01.004.

Van Doormaal, 2010
Ans van Doormaal, Martijn van der Voort, *Methodology to determine probits for glazing failure and hazard*. 34th DDESB Explosives Safety Seminar 2010.

CONSEQUENCE ANALYSIS FOR OUT OF AREA FIELD STORAGE

DDESB seminar
July 14, Portland (Oregon)

TNO | Defence, Security and Safety

Martijn van der Voort (TNO, NLD)
Peter Kummer (BK&P, CHE)
Philip van Dongen (TNO, NLD)

Contents

- Introduction
- General outline of the method
- Effect and consequence modeling
- Results
- Conclusions

Introduction

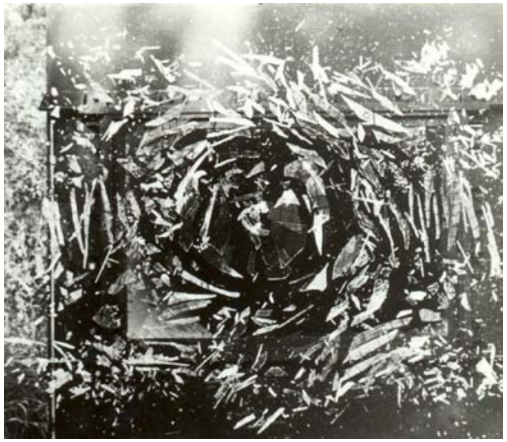
- AASTP-5, Part II
  - NATO guidelines for storage, maintenance and transport
  - During deployed missions
  - To be used by the Operational Commander’s specialist

- Field Distances (FDs)
  - Between PES and PES (preventing propagation)
  - Between PES and ES (ensuring safety level of personnel)

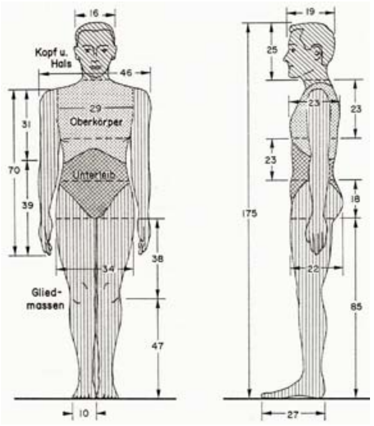
- When FDs can not be applied
  - Lack of area
  - Tactical mission requirements

⇒ Consequence / Risk analysis

Introduction

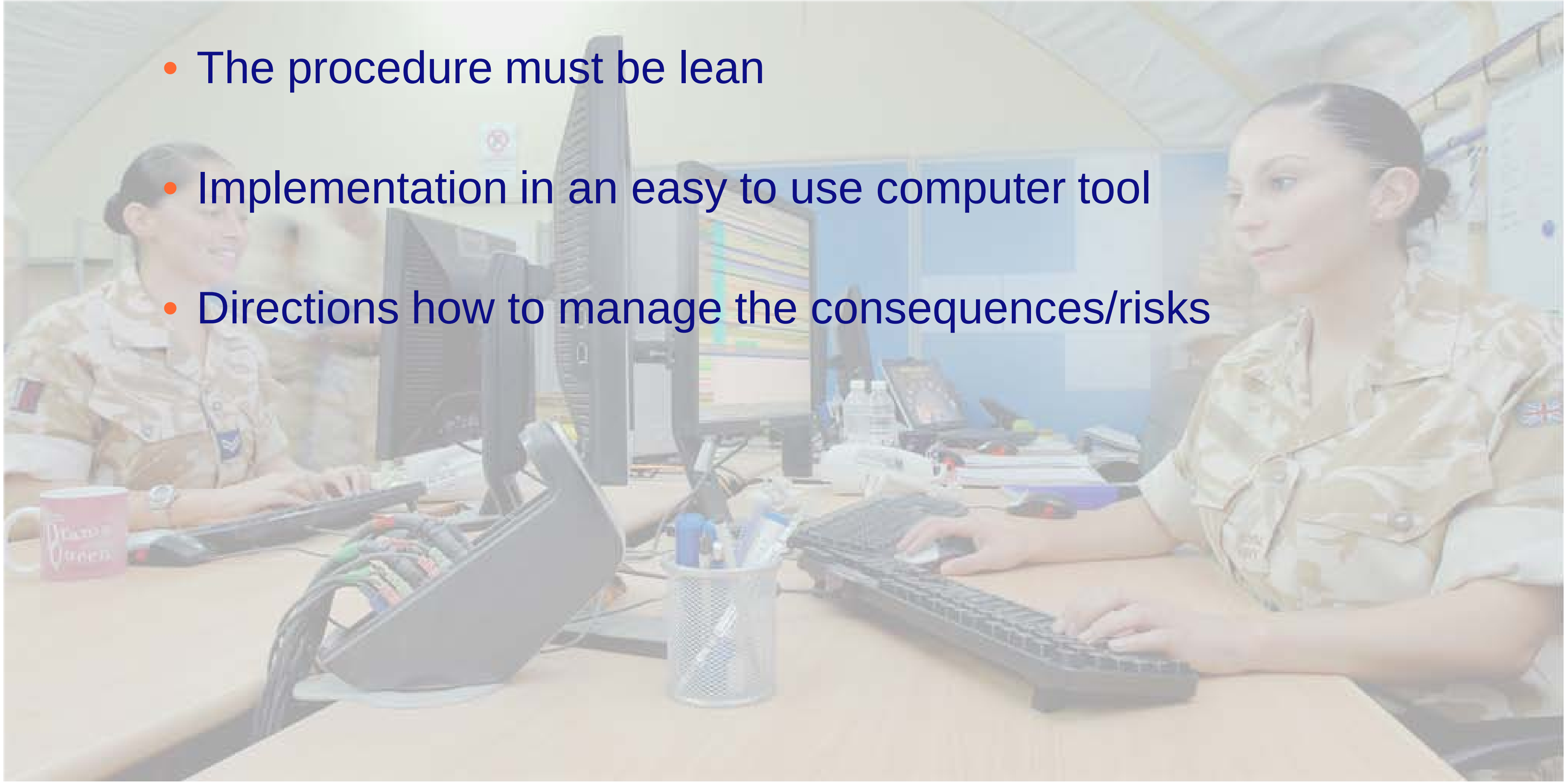


- Development of Consequence Analysis Method
  - AC/326 tasked BK&P and TNO
  - Sponsored by CHE and NLD MoD
- CHE developed general outline of the method
  - Proposition for Risk Analysis chapter
- NLD calculated explosion effects and consequences
  - Lethality and Injury
  - Structural damage



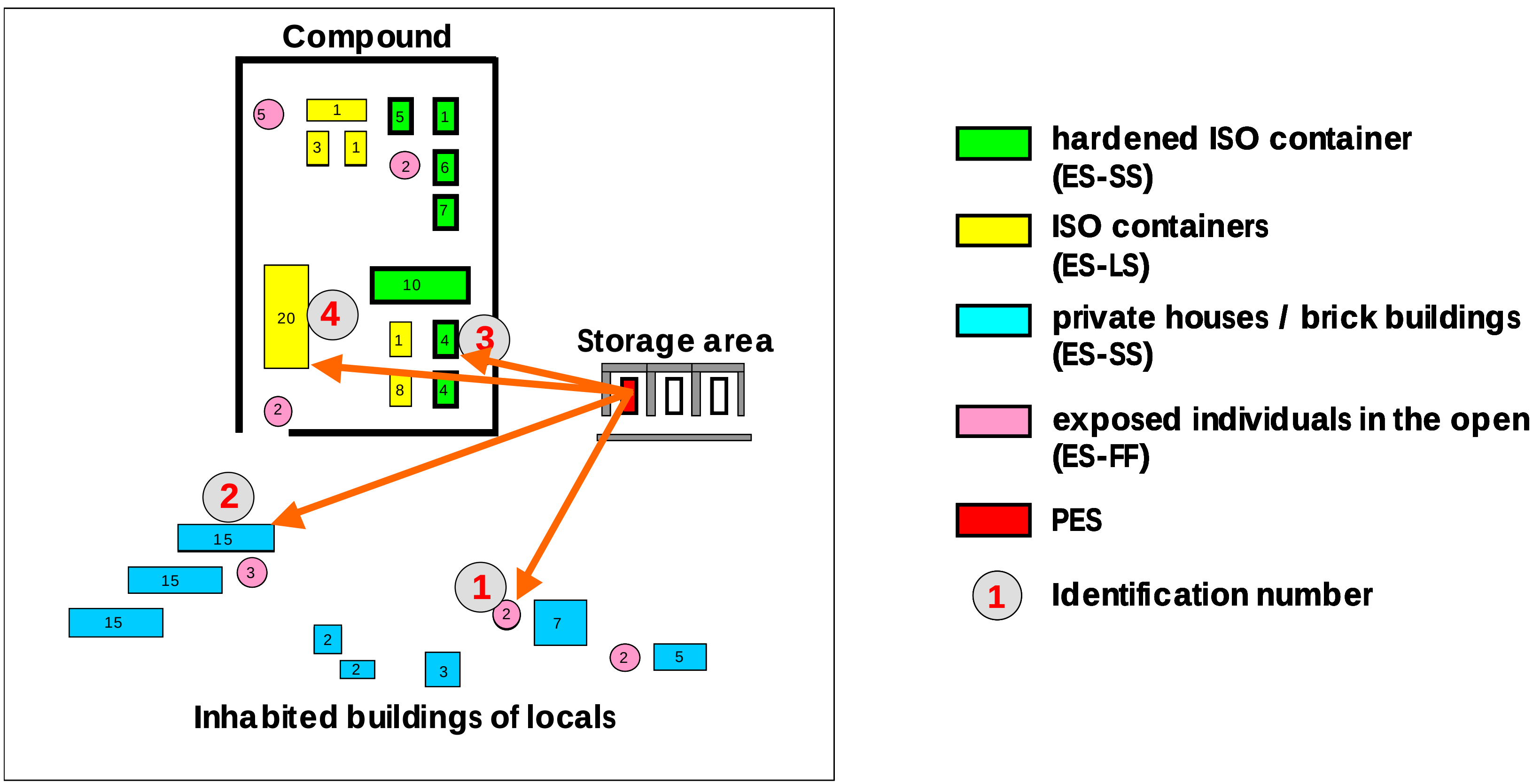
General outline of the method

- Basic requirements
  - Quantitative, concise and convincing
  - Easy to carry out and understandable
  - The procedure must be lean
  - Implementation in an easy to use computer tool
  - Directions how to manage the consequences/risks



General outline of the method

- Step 1; collect data on:
  - Type, location and loading (NEQ) of PES
  - Type and location of ESs
  - Number of persons in each ES
  - Distance between PES an all ESs



General outline of the method

- Step 2; Determine lethality, injury and damage for each ES, based on:
  - Type and loading (NEQ) of PES
  - Type of ES
  - Distance between PES and ES

  With Tables or Excel Tool

1-FF	Parking Lot	125 m
2-SS	Inhabited Building	170 m
3-SS	Sleeping Container	105 m
4-LS	Canteen	145 m

Fiction values!

Lethality Table		CB-4000		
PES - 20ft - Container with Barricade			NEQ = 4000 kg	
Distance	Exposed Sites			
between PES and ES [m]	ES-FF free field [%]	ES-LS light structures [%]	ES-SS semi-hardened structures [%]	ES-HS hardened structures [%]
0 - 10	100	100	100	100
10 - 20	100	100	100	80
20 - 30	100	100	80	50
30 - 50	100	80	50	10
50 - 75	100	50	25	5
75 - 100	100	25	10	1
100 - 150	50	10	2	0.1
150 - 200	10	2	1	0
200 - 300	5	1	0.1	0
300 - 500	1	0.1	0	0
500 - 750	0.1	0	0	0
750 - 1000	0	0	0	0

General outline of the method

- Step 3; Assess the lethality for a given situation by:
  - Fill the lethality values into the consequence calculation table
  - Multiply by the number of exposed persons in the respective ESs
  - Add these results up for all ESs

  Do the same for injury and damage

Fiction values!

Location: Compound NewLand

Case Number: 101

Case Description: Average consequences due to an explosion in container 1

PES Type: barricaded ☒ unbarricaded ☐

PES Number: Container 1

NEQ [kg]: 4000 kg

Map Scale 1: xx

Analysis performed Date: by:

Object No.	Object Type	Object Description	Distance PES - ES [m]	No. of Table used	Lethality [%] A	Number of Exposed Persons B	A x B [%]	Re-marks
1	ES - FF	Parking Lot	125		50	2	100	
2	ES - SS	Inhabited Building	170		1	15	15	
3	ES - SS	Sleeping Container	105		2	4	8	
4	ES - LS	Canteen	145		10	20	200	1)
		Total of all exposed objects				Σ AxB = C	323	
		Expected number of fatally injured persons				C / 100	3	

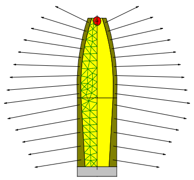
Remarks:

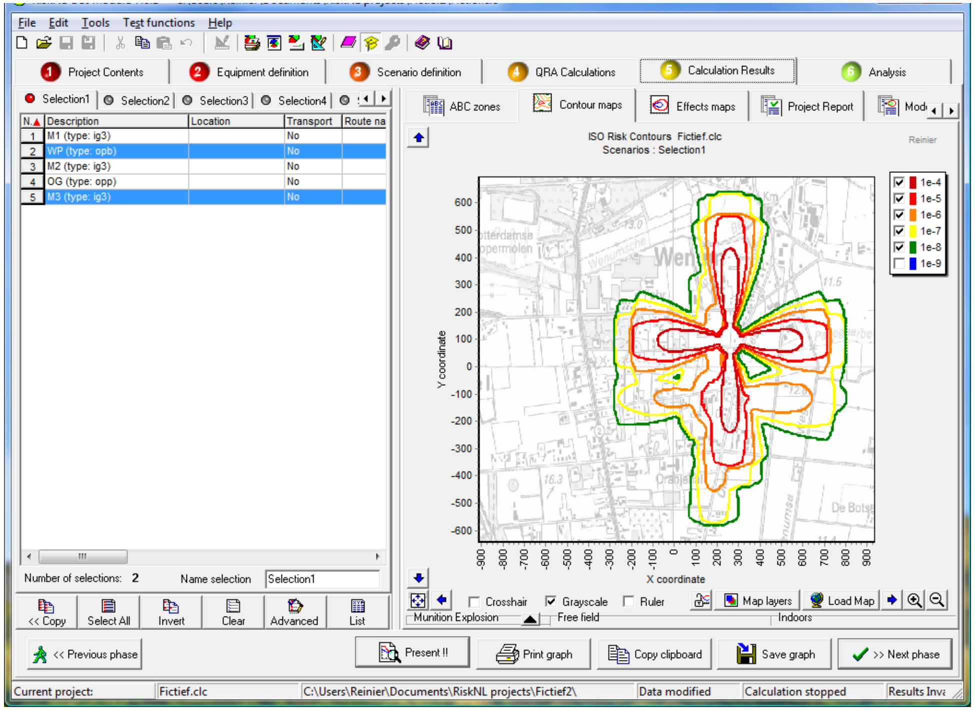
1) 25 persons during daytime, 15 persons during night time = 20 persons in average

Appro-ved: Date: Signature:

Effect and Consequence modeling

- Risk-NL v5.0
  - For QRA (Quantitative Risk Assessment)
  - For external safety in <u>urban</u> area’s
  - Has a.o. a validated PES model for
    - HD1.1 in ISO container
  - ES models for
    - Free field (FF)
    - Inhabited Building (IB)
- Extension with:
  - OoA ES structure types
  - Injury modeling





Effect and consequence modeling

- 6 OoA ES structure types
  - Tent
  - Light (LS)
    - 12.5 mm multiplex / 0.75 mm steel
  - Normal (NS)
    - ISO, 2 mm mild steel
  - Reinforced (RS)
    - 5 mm mild steel
  - Heavily Reinforced (HRS)
    - 2*8 mm armoured steel
  - HESCO
    - 0.8 m sand

Tent

Normal, ISO (NS)

HESCO

Heavily Reinforced (HRS)

Effect and consequence modeling

- Protective measures at ES
  - Barricades (HESCO)
  - Over Head Protection (OHP)
  - Blast resistant windows or no windows

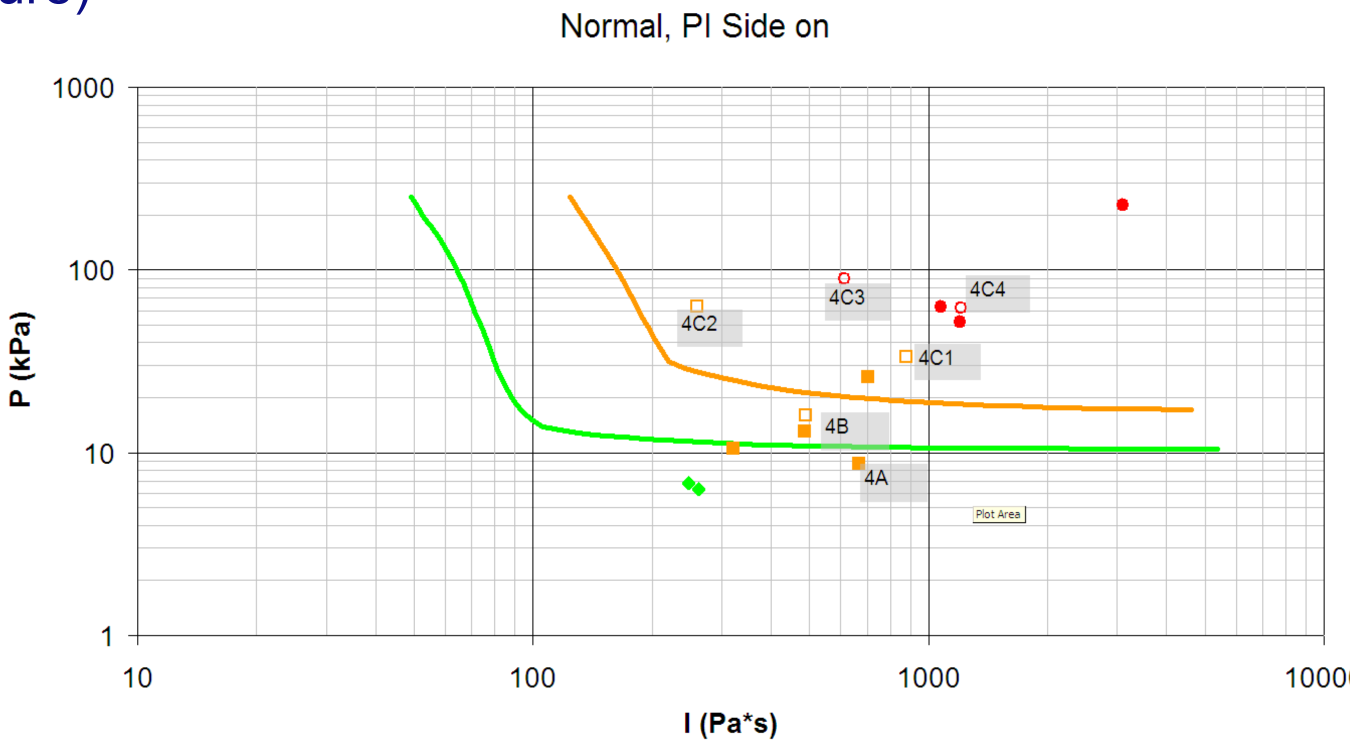
Medical facility with windows

Barricades and OHP

Effect and consequence modeling

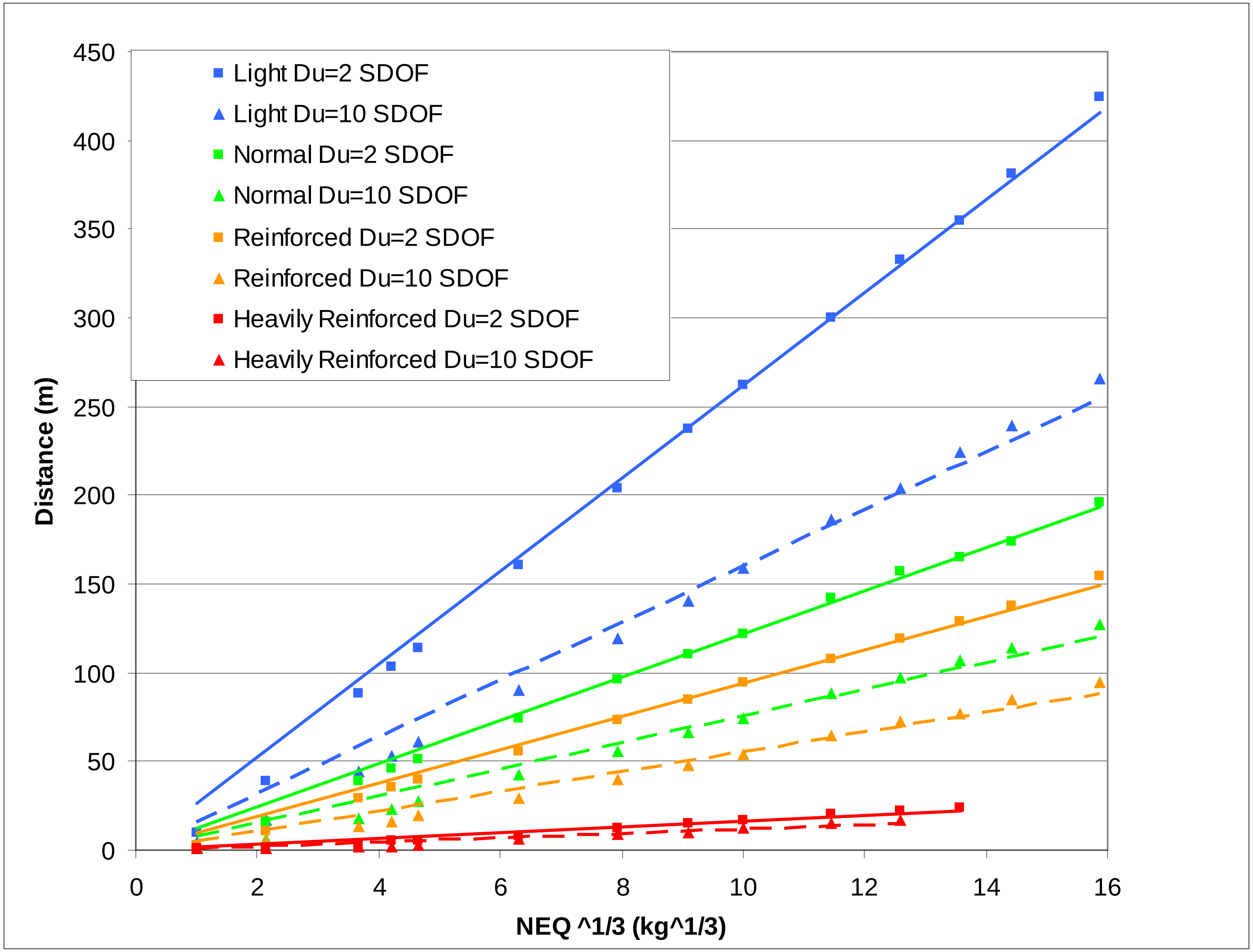
- Prediction of blast and ballistic resistance
  - Based on:
    - Experimental data (TNO Out-of-area database)
    - Structural response calculations and penetration relations
- Damage expressed in Ductility
  - Du ≥ 2 (Damage)
  - Du ≥ 10 (Failure)

Example: ISO containers



Effect and consequence modeling

- Damage and Failure threshold versus NEQ$^{1/3}$



Effect and Consequence modeling

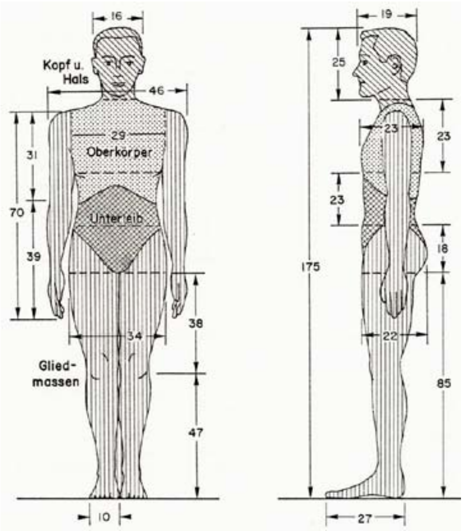
- Overview of injury types

Physical effect	Situation of personnel	Relevant Types of Injury: Auditory	Internal organs	Blunt impact (Whole body displacement)	Glass shard penetration (Window failure)	Blunt impact (structural damage/failure)	Fragment/projectile penetration	Skin burns	Intoxication / Asphyxia
Blast load	Free field	X	X	X					
	Inside structure (with blast damage)	X	X	X	X	X			
Fragment/ Projectile load	Free field						X		
	Inside structure (with penetration damage)						X		
Thermal load	Free field							X	
	Inside structure (without ventilation / fire resistant doors)							X	X

Effect and Consequence modeling

- Injury expressed in Abbreviated Injury Scale (AIS)
  - AIS ≥ 1 (Injury)
  - AIS ≥ 5 (Lethality)

- Fragment impact
  - Lethality for impact at head, thorax, abdomen
    - ~ 40 % of NATO body area 0.56 m^2
  - Injury for other body parts

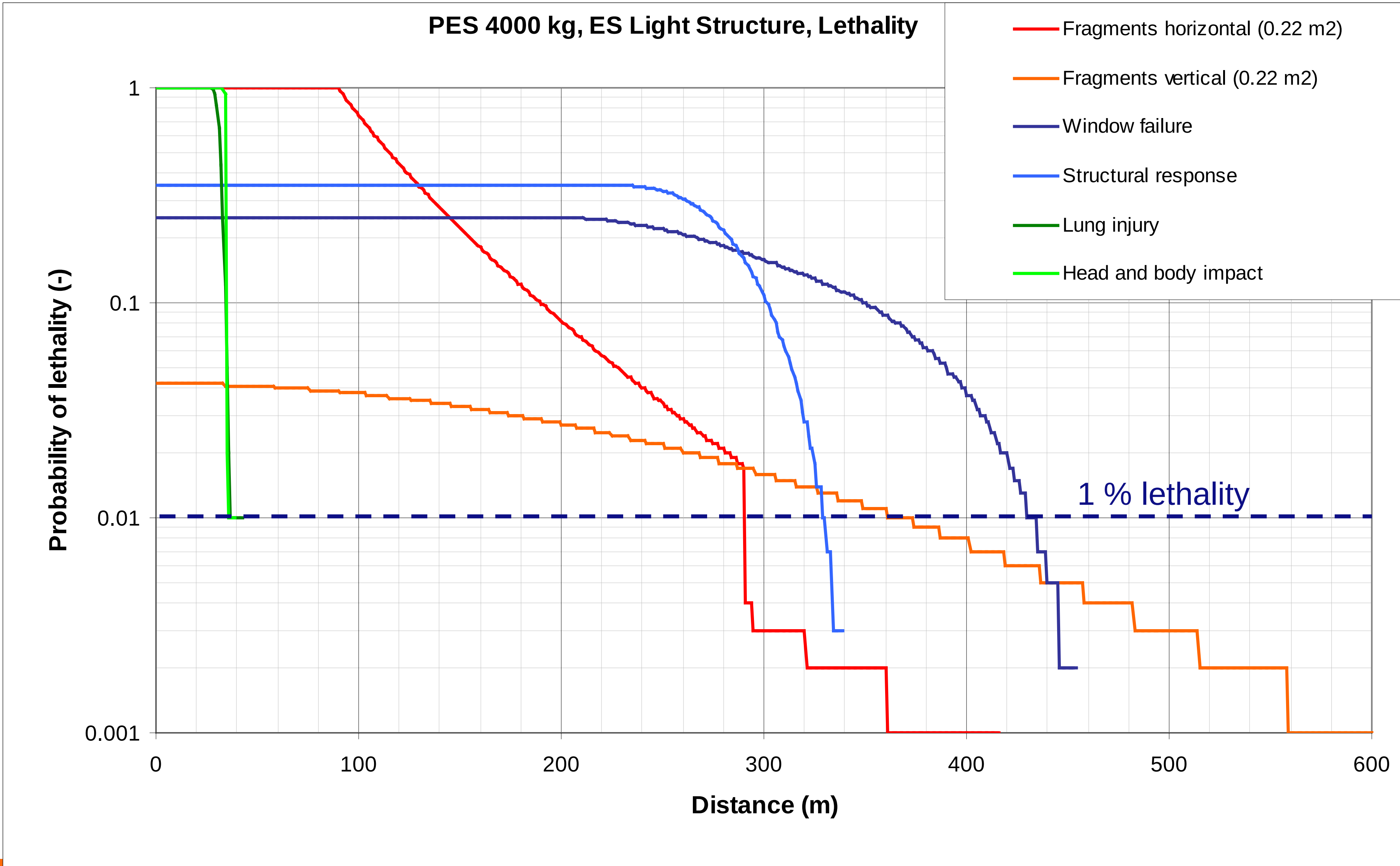


- Structural damage and failure
  - Lethality estimation at threshold values
  - Probit function

- Window failure
  - Lethality model for OoA windows
  - Probit function

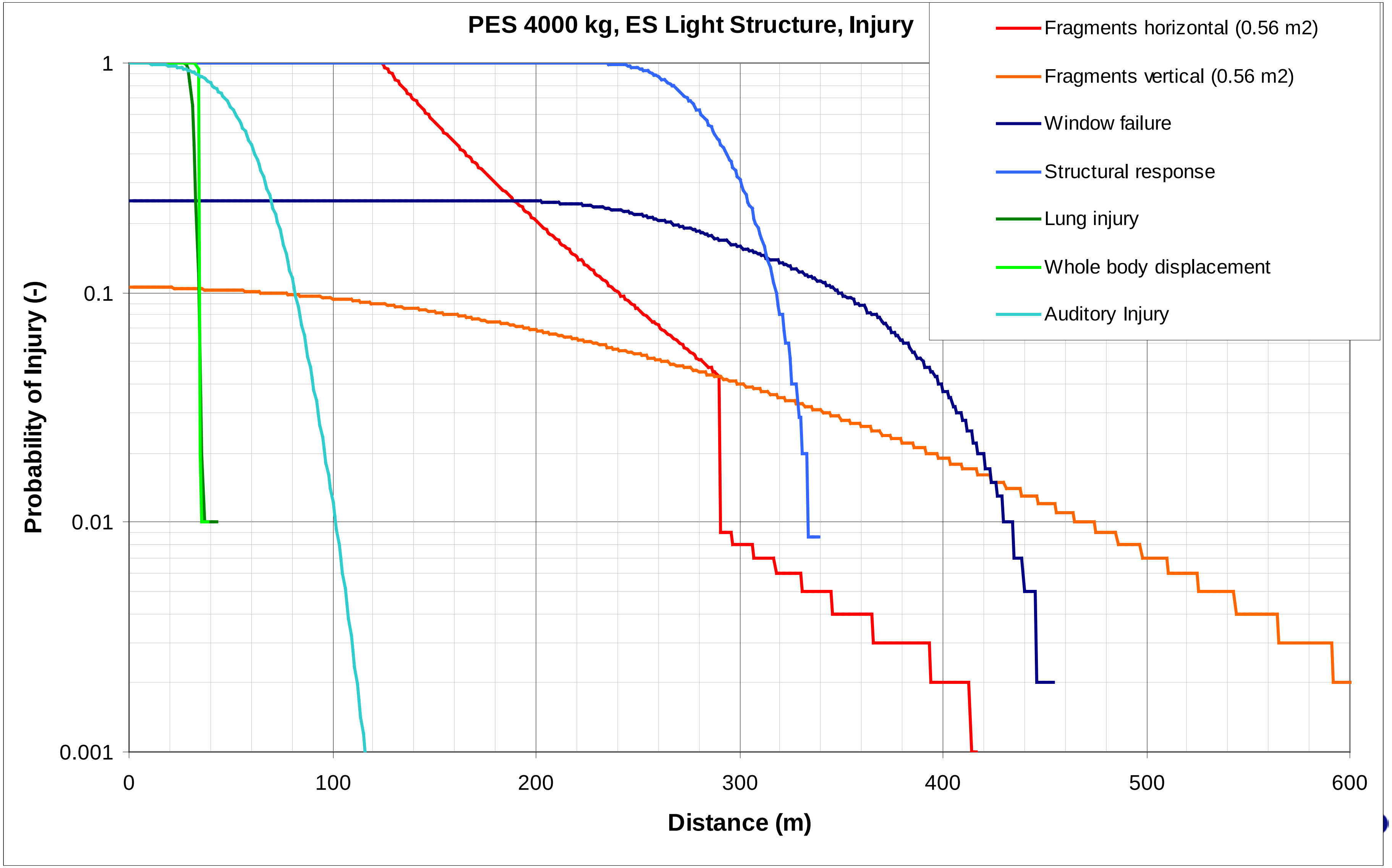
Results

- Detonation of ammunition storage with 4000 kg
- Lethality (AIS ≥ 5) in Light Structure due to various injury types



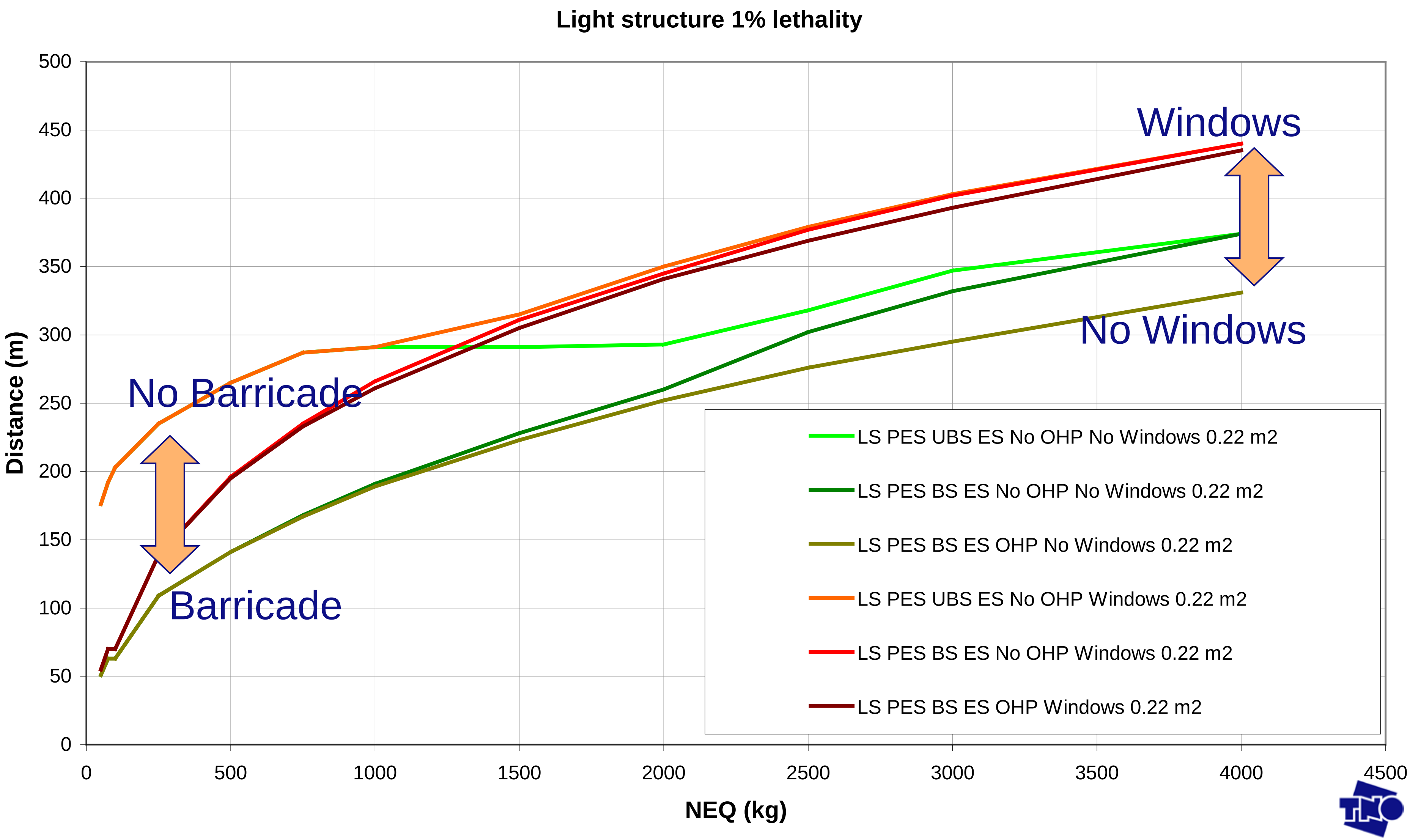
Results

- Detonation of ammunition storage with 4000 kg
- Injury (AIS ≥ 1) in Light Structure due to various injury types



Results

- 1 % lethality distance for Light Structure



AASTP-5 Consequence analysis tool

Microsoft Excel - AASTP-5 risk analysis tool v0.12, Example Compound Newland.xls

Potential Exploding Site (PES, donor)		Location of PES	
Name	NEQ / kg	x-coord. / m	y-coord. / m
Container 1	4000		
Container 2	50		
PES03			
PES04			
PES05			
PES06			
PES07			
PES08			
PES09			
PES10			

PES selected for calculations			
Container 1	4000	0	0

Exposed Sites (ES, acceptors)						Distance from PES or coordinates of ES	Number of persons			Damage
Name	Structure	Barricade	OHP	Windows	Persons	Distance or y-coord. / m	killed	injured	unharmed	level
Parking lot	FF	Barricaded	No OHP	No windows	2	140	0.1	0.1	1.8	Undamaged
Inhabited building	IB	Barricaded	No OHP	Windows	15	200	3.9	0.2	10.9	Damaged
Sleeping container	NS	Barricaded	No OHP	No windows	4	30	4.0	0.0	0.0	Collapsed
Canteen	LS	Barricaded	No OHP	No windows	20	100	7.5	12.5	0.0	Collapsed
ES05										
ES06										
ES07										
ES08										
ES09										
ES10										
ES11										
ES12										

Hesco
HRS
RS
NS
LS
Tent
FF
IB

53 ES26

Results for ES

Number of persons killed, injured or unharmed: calculated effects for the ES.

Title | Instructions | Consequence analysis | Calculation_1 | Layout design | AASTP-5 Table 5.1 | Calculation_2 | Tables | Hesco_4000 | Hesco_3000 | Hesco_2500 | H

Ready

Conclusions

- A consequence analysis method for field storage
- The method consists of tables for a variety of
  - NEQ
  - ES structures
  - physical protection measures (barricades, OHP, window design)
- Calculations with Risk-NL v5.0, extended with:
  - Out of Area ES structures
  - Injury
- Multiple types of injury simultaneously relevant
- Detailed calculations required to account for protection measures
- AASTP-5 Consequence analysis tool is currently being developed
- Future steps towards risk are planned!